Ecosystem engineering: how the Suez Canal changed the sea

Humans have been dramatically altering the Earth's surface since the first farmers took to taming the land. Since then buildings have risen, mountains have been bored and great continents have been carved apart. The Suez Canal, which joined the Red Sea with the Mediterranean some 140 years ago, was an amazing feat of engineering, but it irreversibly altered the biology of the Mediterranean basin. A new study published in Frontiers in Marine Science reveals how human activity following the canal's construction is changing the shape of the Mediterranean Sea.

Beneath the sea's surface, invertebrate larvae drift along the currents. As adults many of them won't be able to move far. Some won't be able to move at all, so this is their chance to spread as they bring their genes to a new stretch of the sea. Fish, on the other hand, swim freely in the ocean, their only hindrance being where the sea meets the land and they can swim no further. Humans, for the most part, move on the ocean in vessels capable of carrying them, their cars and cargo. Land barriers also get in their way, but unlike fish, humans have the ability to break through them.

In 1869, engineers did just that. They dug, dredged and flooded a 164-kilometre-long channel between the Red and Mediterranean Seas to form the Suez Canal. This act of engineering created a 7,000 km shortcut in the trade route to India and still presents a vital trade link between Europe and the Middle East. But the channel provides a highway for more than meets the eye. Since its construction, over 400 alien species have spread from the Red Sea to the Mediterranean, and are building strongholds in the sea's eastern margins. Some of these species are fundamentally altering Mediterranean ecosystems.

This move to the Med is known as Lessepsian migration, after Ferdinand de Lesseps, who managed the canal's construction, and most of it has occurred in the last 50 years. Most species move along the Suez in one direction. The Red Sea is extremely salty and nutrient-poor, so any species hoping to spread from the Med to the Red is faced with a more challenging environment, and one that they are not well equipped to handle. Those going the other way, however, are rewarded with a sea rich in nutrients.

While some alien species can have a positive impact on an ecosystem, either by fulfilling a need in an area under stress, or by providing an additional food source, others can become invasive, displacing native species and degrading local habitats. Roughly one fifth of the known species in the Mediterranean Sea aren't found anywhere else in the world, but many of these are at risk of being outcompeted by new arrivals from the Red Sea. Indeed, in certain areas, where there is a high concentration of alien species, they have caused a shift to a completely new habitat.

The Suez Canal, which now stretches some 193 kilometres from the Red Sea to the Mediterranean, provides a highway for ships and invasive species alike. (Credit: NASA)

In the easternmost part of the Mediterranean, fish trawls close to the coast land a catch containing so many alien species that they outnumber the natives. Some of the most destructive migrants to make the journey from the Red Sea are rabbitfish. Named for their rabbit-like mouths, these voracious herbivores graze on lush brown algae to get their energy. But in some areas, their grazing is so intense that large stretches, once covered in a rich algal carpet, are now barren rocky zones. These fish are critically altering shallow habitats in the eastern Mediterranean, and their impact is likely greater than all the alien fish in the Med combined.

Using data from the European Alien Species Information Network, Stelios Katsanevakis and his international team were able to map

One of the rabbitfish responsible for severely degrading algal forests in the eastern Meddіteranean. (Credit: Roberto Pillon)

how human activities have helped spread non-native species in the Mediterranean. While the canal provides a highway for marine migration, alien species don't have to make the journey alone and many hitch a ride on shipping vessels, either on their hulls or in their ballast water, bringing new species to far stretches of the Mediterranean Sea. Some 300 species have made it to the Med as stealthy passengers and have established themselves around the sea's major ports and harbours.

The Red Sea isn't the only source of alien species. Around the world, ships shift cargo and vast volumes of oil from one coast to another and with each journey they carry the risk of introducing a new species when they come into port. One such hitchhiker is the invasive Australian grape algae, which smothers local algae communities and is now widely established along the Mediterranean coast.

Humans are aiding the spread of alien species further through aquaculture, where species are brought to a new site as commodities and contaminants, though this route makes up a much smaller contribution than shipping and the Suez. And while measures are in place to reduce the risk of alien species introduction, preventing the spread of yet more invasives in the sea is an impossible task. As the climate warms, conditions in the Med will be even better for Lessepsian migrants, so the problem – considered to be one of the greatest biogeographic changes on the planet – is set to worsen.

When we look back at the fossil record, we can see where species originated, expanded and increased their range – changes that have happened over hundreds to millions of years. If we were to look back at our impact on the planet, even in the last century alone, we would see astounding shifts in species, not only in the ocean, but also on land. Together with the collapses brought about by hunting, fishing, habitat change and more, this record is worthy of the name Anthropocene.

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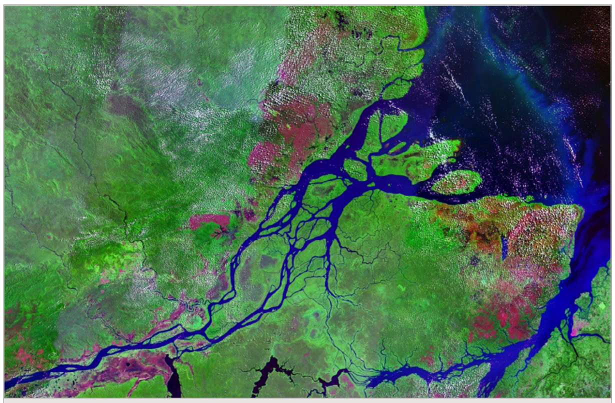
The Amazon and the Anthropocene

The Amazon rainforest covers seven million square kilometres of the Earth's surface. It contains 2,000 different species of birds and mammals, 40,000 plant species, and around 2.5 million insect species. It is surely one of Earth's few remaining natural paradises.

Or is it? Many natural landscapes, including the Amazon rainforest, are readily romanticised in the popular imagination. But by the 1970s we had began to realise that human activity in the Amazon is not just a recent phenomenon; the Amazon isn't as pristine as we had supposed. According to Anna Roosevelt, Professor of Anthropology at the University of Illinois in Chicago, and others, the Amazon was home to as many as five million people in AD1500 and evidence of human presence extends back at least 13,000 years.



Satellite image of mouths of the Amazon River in Brazil. (Credit: NASA)

The start of the Anthropocene epoch is much debated: some scientists believe it should coincide with the start of the Industrial Revolution, whilst others suggest an Early Anthropocene, beginning thousands of years previously. However, a growing body of evidence from the Amazon would seem to imply that human impacts can be traced back a long way – evidence that would therefore support the Early Anthropocene hypothesis. So how do we know about these human activities?

Two lines of evidence are crucial: the soil and the trees themselves. So-called anthropic black soils are, in essence, buried rubbish dumps from former settlements. They tend to consist of ash, fish bones, manure, excrement and burnt plant materials, resulting in a nutrient and carbon-rich soil. Fragments of pottery have confirmed that these soils are of human origin. Some of the best studies have conducted detailed stratigraphic analysis of these soils and their surrounding horizons, anlaysing artifacts from individual layers and dating the sediments to build up a complete history of occupation.

Geoglyphs on deforested land at the Fazenda Colorada site in the Amazon rainforest. (Credit: Sanna Saunaluoma)

Furthermore, they appear to be widespread: as much as ten percent of Amazonia may be covered by anthropic black soils.

The second clue is more subtle. The first human inhabitants of the Amazon, the Paleoindians, are thought to have been foragers, eating fish from the rivers and fruits and nuts from the trees. But when populations began to settle they would cut wood and discard seeds in the vicinity of their settlement. Over time this would have changed the make-up of the forest, producing small concentrations of palm groves and fruit trees. The Amazonian rainforest is traditionally thought to be very diverse such that individual trees in any one particular species are widely spaced. Therefore, concentrations of a specific species are very noticeable. Some of the groves that were created at prehistoric settlements are still intact today and are now major resources. However, the extent of these anthropic forests isn't known and a major challenge for future research is to map their distribution across the entire Amazon basin since doing so would give an indication of the extent of human settlement.

Since the first sedentary sites around 9,000 years ago, there are numerous other indications of large human communities in the Amazon. The oldest of these is from the Faldas de Sangay culture in Ecuador: between 1400 and 2700 years ago an urban-scale development of soil mounds and connecting roads existed in the middle of the western Amazon jungle. The requisite anthropic black soils have been discovered on the tops of the mounds along with fine art, pottery, sculptures and tools. Meanwhile, at Marajo Island, right at the mouth of the Amazon River, more than 400 earth mounds have been discovered over an area of 20,000 square kilometres and are up to 1300 years old. Discoveries like these came as a real surprise: until lately it had been thought the soil quality throughout much of the Amazon was too poor to support static societies of any great size, but these and other major earthworks would seem to suggest otherwise.

The most curious signs of human habitation, though, are features called geoglyphs, large-scale designs etched into the ground. The Nazca Lines, in the Nazca Desert of southern Peru, are probably the most famous example. But in the dense jungle of the Amazon, it is only recently that whole series of geometric shapes have been revealed due to the ongoing deforestation. Now, hundreds of these enigmatic structures have been discovered hidden beneath the canopy. One of the clearest is at Fazenda Colorada in the state of Acre on the western tip of Brazil. A giant circle, diamond, and square were dug into the ground more than a thousand years ago. Their purpose is much debated in the academic literature, but it has been suggested that they might serve a religious or political function.

The research that has accumulated over the last few decades is incontrovertible: the Amazon is not the untouched, exotic paradise we thought it was. Furthermore, the long history of human habitation in the Amazon indicates that people in former ages were able to live in the forest, changing its composition and structure in a way that was compatible with its survival. Perhaps we ought to be trying to do the same?

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No black-and-white issue: how dark aerosols affect the icy heights of the Himalayas

More than a billion people depend on water that runs off from the glaciers of the Himalayas for drinking water, irrigation and hydroelectric power. However, the pressures placed on this enormous water resource by anthropogenic climate change are still surprisingly poorly understood. The importance of better quantifying the effects of human-made changes and their future impacts is clear: not only do more people depend directly on the ice in Earth's 'Third Pole' than that in Greenland or Antarctica, the complex topography of the Himalayas also means that it is impossible to extrapolate from relatively few studies to a larger scale.

An aerosol known as black carbon – droplets or particles of soot suspended in the atmosphere – is of particular concern. A by-product of the incomplete combustion of fossil fuels, it is the most light-absorbing aerosol we know. Emissions of black carbon have skyrocketed over the last 250 years, coinciding with the beginning of

Light absorbing impurities in snow are present on snow and glacier melt in the mountains and polar regions of the globe. This picture shows the Colorado Rocky Mountains snowpack with dust from deserts of the western US. (Credit: T. H. Painter, Snow Optics Laboratory, JPL/Caltech)

the industrial revolution. Some argue that the proposed Anthropocene era should cover this period because of the way in which we humans have shaped the Earth system since the onset of industrialisation. Others suggest that the Anthropocene began much earlier and spans several millenia, but as far as black carbon emissions are concerned, the last two centuries mark a significant deviation from background concentrations. Now, the impact of black carbon on high Himalayan glaciers is the focus of a recent study published in the journal The Cryosphere.

Black carbon has been found to be the second most important anthropogenic emission – behind carbon dioxide, but ahead of methane – in terms of its impact on global radiative forcing. This means that it increases the amount of solar radiation absorbed by the Earth system instead of being reflected back into space. But black carbon has been found to remain in the atmosphere for much less time than previously thought.

The short residence time of black carbon in the atmosphere means that large amounts of the material are deposited on the ground – or, in the case of the Himalayas, on snow or ice. The black particles lower the albedo of the white ice and snow, meaning that far more solar radiation is absorbed rather than reflected. To quantify how much extra melting black carbon has caused in the Himalayas over the last decade, Patrick Ginot of the University of Grenoble and his co-investigators studied a shallow ice core containing ice accumulated from 1999 to 2010 at the summit of Mera Peak in northeastern Nepal, at 6,376 m above sea level.

The researchers chose the inaccessible study site on purpose. Very few studies of the impact of black carbon on glacier mass balance exist from altitudes of above 6,000 m, where its aerosol effect increases considerably. Since ice persists year-round, black carbon deposits become part of the layers of ice as they accumulate year after year; its abundance can be measured in the ice core. Finally, Mera Peak is situated on the south side of the Himalayas, where the monsoon and the westerly winds that prevail during the rest of the year supply air from different parts of the world and with different black carbon concentrations.

Measuring the concentrations of black carbon and dust in the ice core, Ginot and his colleagues found that black carbon peaked immediately before and after each monsoon. During this time, air is transported up from India and displaces the westerly winds that usually dominate. During the monsoon itself, however, black carbon is washed out of the atmosphere by rain before the air reaches the Himalayas.

Despite its strong effect on albedo, black carbon proved not to be the only important driver of changes in ice melt at the summit of Mera Peak. The amount of dust, another material that lowers the albedo of ice, was up to 1,000 times greater than the amount of black carbon in the ice core. Using models to simulate the energy balance of the glacier and the net amount of energy available for melting, the researchers calculated that black carbon and dust together could have caused up to a quarter of all ice melt over the 2009–10 period.

The consistently high levels of dust throughout monsoon and non-monsoon periods suggest that its source is local and relatively nearby. To verify whether the strong contribution of dust to glacier melt is a local anomaly, Ginot and his colleagues plan to collect another ice core from a different high-altitude site.

While the team did not detect a rising trend in the black carbon content of the ice at Mera Peak over the last decade, the subject warrants further study, particularly as black carbon patterns are known to be much more complex in the Himalayas than in the other two great reservoirs of ice in Greenland and Antarctica. It remains to be seen whether measures to cut down black carbon emissions in India and worldwide will continue to be effective. If concentrations of this dangerous aerosol can be reduced, millions of people may continue to rely on the mighty rivers flowing down from the Himalayas as their main water source.

The number of ways in which the growing human population has affected the Earth system in the last 10,000 years is beyond counting, making an exact definition of an era such as the Anthropocene a challenging issue. This study of black carbon in the Himalayas contributes to one of the most prominent debates at present, relating to emissions of aerosols such as black carbon and other particles contributing to global climatic change over the last few centuries.

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